Operating a Brain Computer Interface: Able Bodied vs. Physically Impaired Performance

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Abstract : Brain-computer interface technology enables people to interact with computers using their brainwaves and has applications in assistive technologies for the physically impaired, rehabilitation after stroke and in non-medical applications such as games and entertainment. Voluntarily modulation of sensorimotor rhythms (SMR) form the basis of non-invasive (EEG-based) motor imagery (MI) BCIs. Planning and execution of hand movement are known to block or desynchronize neuronal activity which is reflected in an EEG bandpower decrease in mu band (8-12Hz). Inhibition of motor behaviour synchronizes neuronal activity [1]. During unilateral hand imagination, the preparatory phase is associated with a contralateral mu and central beta event related desynchronization (ERD) that is preponderant during the whole imagery process [2][5]. BCIs have primarily been tested on able-bodied users however a range of studies with those suffering from locked in syndrome as a result of motor neuron disease or brainstem stroke [2][3] have been conducted along with spinal cord injury studies [4]. Performances of able-bodied users vary significantly as does the performance difference between different users groups i.e., including able-bodied and physically disabled. It is therefore important to account for any differences in performance when developing a BCI for a specific user group, using able-bodied subjects during the R&D stage to gauge the appropriateness of methods and procedures. For example, physical injuries such as spinal cord injury or stroke can result in changes in the organization of the primary sensorimotor cortex and the function of the sensory and motor pathways [6][7][8][9]. Functional MRI (fMRI) studies have also identified significant derangements such as, a strongly reduced volume of activation, degraded modulation of sensorimotor function and abnormal activation patterns for different MI tasks [10]. It has been observed in the upper-limb amputees using positron emission tomographic (PET) measurements of regional cerebral blood flow (rCBF) that there is an increased activity in the partially deafferented primary sensorimotor areas when upper-limb amputees move areas near the injury or have those areas stimulated [11][12]. Paced shoulder movements have been associated with significant blood flow increases in the contralateral M1/S1 cortex of amputees [11]. This phenomenon has not been observed using EEG signals so far.

Objective: The aim of this study was to compare BCI performance and to analyse the differences in the organization of event related synchronisation/desynchronisation (ERD/ERS)[2][5] for able bodied (AB) subjects vs. physically impaired (PI) subjects when using a BCI over an extended duration.

Design: Group comparison

Participants: A meta-analysis was carried out between the two groups. Both groups had no prior experience of using a BCI. The AB group included ten abled-bodied individuals, 50% male/female, aged 19-38, recruited in Northern Ireland. The PI group consisted of nine subjects with cervical spinal cord injuries ranging from C3 to C6 and one patient with locked-in syndrome as a result of bilateral thalamic and brain stem strokes, 80% male, aged 24-61, recruited through the National Rehabilitation Hospital of Ireland. Ethical approval was granted by the National Rehabilitation Hospital Ethics Committee and the University of Ulster's Research Ethics Committee.

Setting: The AB group experiments were conducted in a BCI lab at the University of Ulster. It was intended to recruit in-patients for the PI group and conduct experiments at the hospital however, during the recruitment phase the cohort of inpatients were mainly in an older age category (>55yrs) and declined to take part in trials therefore the majority of participants were chronic stage patients attending outpatient clinics and trials were conducted in the patients' homes (trials with a locked-in patient were conducted within the hospital). This provided scope for a real test of the technology. The length of time since injury occurrence ranged from 7 to 35 years. Ten sessions were conducted for each subject over a period of four months.

Methods: A binary class BCI (left vs. right MI) was used in this analysis using three bipolar channels over the sensorimotor cortex (CP3-FC3, CPz-FCz and CP4-FC4 and a reference electrode on the right mastoid). gMOBilab and gBSamp amplifiers from Guger Technologies were used for the PI and AB groups, respectively. A training session involved MI cued by an arrow on the screen with no feedback whilst a feedback session involved controlling a ball on the screen and directing toward a basket using the appropriate motor imagery. Each session lasted approx. 1 hour and each participant took part in a total of 10 sessions. The BCI translation algorithms are presented in [13][14].

Results: The AB group significantly outperformed the PI group in terms of classification accuracy (CA) ($p<0.05$) and ERD/ERS separability for different MIs. Accuracy rates ranged between 55% and 75% for both groups. In terms of ERD/ERS analysis, high frequency band-power activity is observed for the PI group but not the AB group. This increase in band-power activity may be related to the increased blood flow in M1/S1 cortex as revealed in [11][12]. Although there is a higher mu band activity for the PI group, the average absolute distance between the ERD for two classes in the mu band during the event related period is maximal for the AB group indicating that there is less consistency in the ERD in mu band for the PI group than the AB group, resulting in BCI performance inconsistency across the PI group.

Conclusions: These results are obtained as the preliminary phase of a larger study to enable physically impaired users to control a range of applications using a BCI. The results are positive in the sense that the performances of a number of participants from the PI group are comparable to the AB group, even though injuries were acquired 7-35 years prior to the experiments. In such cases SM activation would be limited due to the acquired injury and non-utilisation of affected limbs. The study had a range of limitations which are being addressed in phase two. These include:-

1. The BCI is based on a limited number of channels (3 channels as opposed to other studies which use up 128 channels). Using fewer channels is desirable to limit mounting time and the obtrusiveness of the montage used for future applications. Future work will involve assessing sensorimotor differences in higher resolution EEG recordings (32 channels). This would provide better insight into the exact location of the abnormalities and cortical deficits, neuronal adaption and recruitment and the reasons for the lower performance and higher bandpower activity in paralyzed patients.
2. In this study, in most cases, it took 3-4 months to complete the 10 sessions. Feedback sessions were not conducted on the same day as the training session which can result in unsuitable classifiers and non-stationarity issues. Phase two will involve a more intensive schedule of trials with a selected number of users conducted within a shorter period (within one week, 1 session per day lasting up to 3 hours and involving both training and feedback, 5 sessions per week). Training the classifier the same day would lead to more stable performance and a better understanding of the BCI usage on daily basis. A number of different BCI applications have also been developed at the University of Ulster, including a wheel-chair simulator and range of gaming applications. These games enhance motivation, interest and performance in the BCI experiments. Wolpaw and McFarland [15] have shown that healthy subjects and spinal cord injury patients usually need several months of training to develop high accuracy (i.e., >90%) using μ and β frequency components and training periods of several months with slow cortical potentials is required to achieve accuracies of 65-80% for healthy subjects. Kubler et al [3] outline a study where the action potential firing rates i.e., an invasive BCI with implanted electrodes, were used by one ALS patient and accuracies of up to 80% were achieved after 1 year. Twelve patients with severe motor total paralysis required up to greater than one year of training to achieve accuracies between 65% and 90% [3]. A study by Pfurtscheller et al. [4] showed that a tetraplegic patient could operate a hand orthosis using an EEG-based BCI with between 90% and 100% accuracy after 5 months of training. BCI control does not work for a non-negligible portion of subjects (estimated 15% to 30%) [16]. Many studies have shown that healthy subjects with a number of feedback sessions completed may still produce unsatisfactory performance and in many cases subjects are hand selected after an initial screening session to determine if the subject can perform motor imagery successfully.
3. Once we have identified applications which users are keen to train on regularly over an extended period we will develop a program for extended usage and training with a subset of willing participants.

4. Conducting trials within patients' homes was a challenge in terms of environmental factors including electrical noise. The setting for in-home experiments is less controllable than for lab based experiments. Future experiments will involve using active electrodes as opposed to passive, which are less susceptible to electrical noise and much easier to setup.
5. As outlined, participants in the PI group were 7-35 years post acquiring the injury. Sensorimotor activations are affected and therefore modulation of sensorimotor rhythms by these users is likely to be more difficult as evidenced by the BCI performance results presented here. We aim to recruit physically-impaired in-patient users in the acute stages of treatment and rehabilitation therapy to determine if BCI usage performance is improved.

References:

[1] G.E. Chatrian, M. Peterson, J.A. Lazarte, "The blocking of the rolandic wicket rhythm and some central changes related to movement," *Electroencephalogr. Clin. Neurophysiol*. Vol. 11, pp. 497‑ 510, 1959.

[2] J.R. Wolpaw, N. Birbaumer N, D.J. McFarland, G. Pfurtscheller, Vaughan T M, "Brain-computer interfaces for communication and control", Clin. Neurophysiol, vol. 113, pp. 767-91, 2002.

[3] A. Kubler, B. Kotchoubey, J. Kaiser, J.R. Wolpaw.] and N. Birbaumer, "Brain-Computer communication: unlocking the locked-in", Psychological Bulletin vol. 127, no. 3, pp. 358-375, 2001.

[4] Pfurtscheller G, Guger C, Muller G, Krausz G, Neuper C. "Brain oscillations control hand orthosis in a tetraplegic", Neurosci. Lett. vol. 292, pp. 211–214, 2000.

[5] G. Pfurtscheller, C. Neuper, D. Flotzinger, M. Pregenzer, "EEG-based discrimination between imagination of right and left hand movement," *Electroencephalography and Clinical Neurophysiology*, vol. 113, no. 6, pp. 642–651, 1997.

[6] C. Enzinger, S. Ropele, F. Fazekas, M. Loitfelder, F. Gorani, T. Seifert, G. Reiter, C. Neuper, G. Pfurtscheller, G. Muller-Putz, "Brain motor system function in a patient with complete spinal cord injury following extensive brain–computer interface training", *Exp Brain Res*, vol. 190, pp. 215–223, 2008.

[7] N. Wijesuriya, Y.Tran, R.A. Thuraisingham, H.T. Nguyen and A.Craig , ", Effects of mental fatigue on 8-13Hz brain activity in people with spinal cord injury", *30th Annual International IEEE EMBS Conference,* pp. 20-24, 2008.

[8] S. de Vries, T. Mulder, "Motor imagery and stroke rehabilitation:a critical discussion", *J Rehabil Med* vol. 39, pp. 5–13, 2007.

[9] M. Bruehlmeier, V. Dietz, K. L. Leenders, U. Roelcke, J. Missimer, and A. Curt, "How does the human brain deal with a spinal cord injury?," *Eur. J. Neurosci*., vol. 10, pp. 3918–3922, 1998.

[10] S.C.Cramer, L. Lastra, M. G. Lacourse MG, M.J. Cohen, "Brain motor system function after chronic, complete spinal cord injury", *Brain* vol. 128, pp. 2941–2950, 2005.

[11] J. J. Kew, M. C. Ridding, J. C. Rothwell, R. E. Passingham, P. N. Leigh, S. Sooriakumaran, R. S. Frackowiak, and D. J. Brooks, "Reorganization of cortical blood flow and transcranial magnetic stimulation maps in human subjects after upper limb amputation," *J. Neurophysiol.,* vol. 72, pp. 2517–2524, 1994

[12] J. J. Kew, P. W. Halligan, J. C. Marshall, R. E. Passingham, J. C. Rothwell, M. C. Ridding, C. D. Marsden, and D. J. Brooks, "Abnormal access of axial vibrotactile input to deafferented somatosensory cortex in human upper limb amputees," J. Neurophysiol., vol. 77, pp. 2753–2764, 199

[13] D. Coyle, J. Garcia, A. Satti, and T. M. McGinnity, "EEG-based Continuous Control of a Game using a 3 Channel Motor Imagery BCI", *IEEE Symposium Series on Computational Intelligence,* pp. 88-93, April*,* 2011.

[14] D. Coyle, "Neural network based auto association and time-series prediction for biosignal processing in brain-computer interfaces", IEEE Computational Intelligence Magazine (invited), pp.47-59, vol. 4, no. 4, 2009.

[15] J.R. Wolpaw, H. Ramouser, D. J. McFarland, and G. Pfurtscheller, "EEG-based communication: Improved accuracy by response verification", IEEE Transactions on Rehabilitation Engineering, vol. 6. no.3, pp. 326-333, Sept. 1998.

[16] B. Blankertz, C. Sannellia, S. Halderd, E. Hammerd, A. Kübler, K-R. Müller, G. Curioc, T. Dickhaus, "Predicting BCI Performance to Study BCI Illiteracy", *BMC Neuroscience* 2009, **10**(Suppl 1)**:**P84